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THE CHEMICAL DOSIMETRY OF IONIZING RADIATIONS.

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There is a lot of fundamental works at present dedicated to the ionisation, calorimetric, scintillation and some other physical methods of dosimetry (see, for example / I-8 /. As a contrast, the rich theoretical and experimental material about chemical methods in dosimetry has not yet been summarized. The problems which can be solved by means of these methods are not defined. Principles of using these methods are not worked out.

An attempt is being made in the present report to consider principal features of the chemical methods of dosimetry, chiefly from the view point of their using during the exploitation of piles when the object is submitted simultaneously for several kinds of irradiation.

The chemical methods of dosimetry are based on the determination of chemical changes in some substances effected by ionizing radiations. A set of chemical methods called chemical dosimetry is one of the parts of applied radiation chemistry.

As far as absorbed radiation energy cannot transform completely into chemical reaction energy, it is necessary to know the ratio of the observed effect and the quantity of the absorbed radiation energy in using chemical dosimetry, methods, like all other methods except calorimetric ones. The ratio usually characterized by the radiation yield value, that is, the number of

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molecules or ions which were formed or changed after absorbing a definite quantity of radiation energy by substance. If the yield value G (moles/joule) for any product of radiation/chemical reaction, the concentration of this product C (moles/cubic meter) and the density of irradiated substance d (kg/cubic meter) are known, then the value of dose can be found from the following equation:

$$D = \frac{C}{G \cdot d} \quad (\text{joule/kg}) \quad (I)$$

The modern chemical radiation theory predicts for many substances the independence of G -values of the kind and energy of radiation, dose, dose power and temperature in a wide interval of values for these parameters. For example, by using concentrated enough aqueous solutions of substances which are powerful acceptors for radical products of radiolysis of water it is possible to prevent its recombination at the most early stage of track existence. In this case the yield of product formed by interaction of the dissolved substance with radicals is completely independent of kind and energy of radiation, dose power and temperature (or depends very little).

In concentrated solutions the dissolved substance can change not only in reactions with radicals, but also as a result of interaction with excited solvent molecules and the "direct" effect of irradiation.

The physical theory shows that the processes of excitation energy transfer and the effects caused by the "direct" action are independent of radiation parameters. Hence, it seems that in using concentrated aqueous solutions it is possible to secure the independence of G -value of the radiation composition and spectrum, dose power and temperature. At the same time, the most complete

using of absorbed radiation energy in chemical radiation processes is secured. This conclusion was experimentally proved by one of the authors together with Cheburkov, Malakhov and Gramolin taking concentrated aqueous nitrate solutions as an object / 9,10 /.

The independence of G-value of changing the most important radiation parameters in wide intervals was also found in many organic systems. Bakh and co-workers / 11,12 / showed that the G-value for oxidation of the crystal violet leucobase in methylethylketone is independent of temperature changes from - 85 up to + 50°C, dose power from $5 \cdot 10^{-4}$ to 0,25 watt/kg and (which is very important) of linear energy transfer (LET) changes from 0,16 to 1,6 aj/nm. The yield value remains constant in the dose interval 0,01-10 j/kg. The experimental data available prove that in some hydrocarbons the yield of molecular hydrogen is independent of LET changes, as well as dose power changes / 13-16 /.

From the dosimetric view-point organic polymers are very interesting since they are available, easily formed by desire and may be used without shielding; also their composition is analogous to the media which are especially often effected by ionising radiation. Unfortunately the literature data about the influence of radiation parameters upon chemical radiation transformations of organic polymers are very restricted and insufficient for definite conclusions (see, for example /17, 18/). Nevertheless, our experiments carried out together with Levon / 19 / showed that in polyvinyl alcohol films containing thiazine and azo-dyes the degree of fading changes very little when the LET value changes by three orders and is practically independent of power dose and temperature changes in wide intervals.

At present the determination of composition and spectrum of incident radiation by computation or experimentally is con-

nected with serious difficulties and is practically impossible in every particular case when the dose value is to be measured, especially in pile experiments. Therefore the physical parameters of dosimetric system and investigated medium must be the same or differ from one another very little. In addition, radiation similarity of dosimetric system and investigated medium must be secured in the conditions of simultaneous influence of several kinds of radiations, and also in conditions when the energy of any kind of radiation may be varied in wide intervals.

The ionisation and scintillation methods, as well as methods where Cerenkov counters, crystal counters and semiconductors are used as detectors, are based on using special equipment. To model different media, detector changing is necessary, even changes in apparatus construction in some cases. However, even these undesirable for practice operations cannot secure necessarily exact model because of restricted possibilities of the very methods in this consideration.

The chemical methods, unlike physical ones, allow to secure a very high radiation similarity degree of dosimetric system and investigated medium. This is governed mostly by two circumstances: 1/ chemical radiation effects appear and can be detected in all complex substances and in some simple substances, independently of their aggregate state; 2/ no special equipment is needed for detecting chemical radiation effects. As a rule, chemical radiation effects can be exactly measured in an ordinary chemical laboratory. In some cases these effects can be determined visually without any equipment, accurately enough for practical purposes.

Owing to the possibility of securing radiation similarity of dosimetric system and investigated medium and independence of

G-value of radiation parameters, chemical methods may be used for dose determination (in j/kg) of different kinds of radiation. Such determinations are not connected with any difficulties and are the consequence of the matter of chemical methods for chemical changes in a given volume of irradiated medium are caused only by the energy absorbed in this volume.

Chemical radiation effects can be detected and accurately determined in volumes of any shape and size. Therefore chemical methods may be used for dose determination in insymmetric volumes as well as anomalous-shape volumes and for the direct determination of absorbed radiation energy space distribution. In principle, the very investigated medium may serve as a dosimetric system when chemical methods are used. Therefore chemical methods may be used for the determination of autointegral doses. Finally, in chemical dosimetry substances may be used which are very resistant against irradiation, this fact allows to apply chemical methods for determining very high radiation doses.

It is necessary to show some interesting features of chemical dosimetry methods.

It is possible to select from the great number of substances used in chemical dosimetry such substances which change in a different way with LET change. Owing to this it is possible by using two dosimetric systems with different radiation yield values under the influence of neutrons (more exactly, protons and recoil atoms, and other products of interaction of neutrons with irradiated medium) and γ -rays to determine the contribution of every component into total dose. Evidently, two independent linear equations can be written:

$$N_i = \frac{G_{\gamma}^i D_{\gamma}}{100} + \frac{G_H^i D_H}{100} \quad (2)$$

$$N_2 = \frac{G''_{\gamma} D_{\gamma}}{100} + \frac{G''_H D_H}{100} \quad (3)$$

From these

$$D_H = \frac{\left(\frac{C_2 G'_{\gamma}}{M_2 d_2} \right) - \left(\frac{C_1 G''_{\gamma}}{M_1 d_1} \right)}{G''_H \cdot G'_{\gamma} - G'_H \cdot G''_{\gamma}} \text{ гж/кг} \quad (4)$$

$$D_{\gamma} = \frac{\left(\frac{C_2 G'_H}{M_2 d_2} \right) - \left(\frac{C_1 G''_H}{M_1 d_1} \right)}{G''_{\gamma} \cdot G'_H - G'_{\gamma} \cdot G''_H} \text{ гж/кг} \quad (5)$$

where N_1 , C_1 and M_1 - number of molecules in cubic meter, concentration (moles/cub.mt) and molecular weight of product formed in one of the dosimetric systems under the influence of mixed radiation; G'_H and G'_{γ} - radiation yields of this product for neutrons and γ -rays, correspondingly; N_2 , C_2 , M_2 , G''_{γ} , G''_H the same values for the product formed in the second system; d_1 and d_2 - densities (kg/cub.mt) of first and second dosimetric systems, correspondingly.

Comparing the data about G-values for some substances under the influence of γ -rays and neutrons, published in literature and the data about relative biological effectiveness (r.b.e) of these kinds of radiation for certain kinds of living organisms, it can be seen that, for example, the hydrogen peroxide yield in water and r.b.e. depend on LET value similarly. Such analogies can be observed in some other cases; the reason for this is evidently similar nature of effects appearing during irradiation of media compared. Therefore chemical dosimetry methods allow direct measurement of biological dose in (j/kg) x r.b.e. units.

At present a great number of chemical dosimetry methods are known; with the help of them measurements of absorbed energy

for different kinds of radiations can be done in a very wide dose interval (from 0,005 to 10^8 j/kg), in an accurate correspondence with the recommendations of GOST-8848-58 and the International Committee on radiology units and measurements. A wide circle of compounds used in modern chemical dosimetry allows to secure in every particular case a very high radiation similarity degree of dosimetric system and investigated medium. Owing to this, data about the quantity of absorbed energy obtained with the help of any dosimetric system can be applied to the investigated medium without extra calculations.

A series of chemical dosimetry methods is characterized by a very high degree of accurateness which at present cannot be obtained by other dosimetry methods. This high accurateness can be reached by using equipment which is simple in construction and work.

It must be also pointed that the possibilities characteristic for chemical dosimetry are at present far not completely realized. For example, only a little part of chemical dosimetry methods cited in literature gives measurement results independent of LET changes. No one of cited chemical dosimetry methods allows to measure biological doses in (j/kg) x r.b.e. units in the dose interval, interesting for radiobiologists.

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